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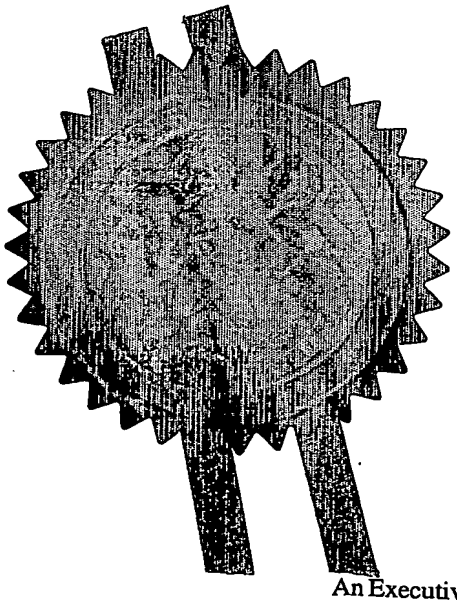

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Patents ADP Number (*if you know it*)
07419294001

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Title of the invention — SIGNAL PROCESSING METHOD AND APPARATUS

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DESCRIPTION

SIGNAL PROCESSING METHOD AND APPARATUS

The present invention relates to a method of signal processing and to apparatus for signal processing.

European patent specification no. EP 0 987 863 A1 describes a system for demodulating a 8-PSK modulated signal involving splitting the symbol into its I and Q components being input as bits into a Viterbi decoder.

An article entitled "Turbo-detection for Enhanced Data for GSM Evolution" by V Franz and G Bauch, IEEE Vehicular Technology Conference, 19-22 September 1998 vol 5 p 2954-8 describes a technique used to improve the equalisation and decoding by an iterative procedure in which the output from a convolutional decoder is re-coded and used to generate symbol probabilities before another attempt at equalisation (followed by another attempt at decoding).

This approach has the substantial disadvantage of requiring considerable processing power.

An object of the present invention is to provide improved demodulation of PSK signals.

Another object of the present invention is to provide improved decoding of transmitted symbols.

Another object of the present invention is to provide improved performance of the transmitted signals.

A further object of the present invention is to provide significant reduction in block error rate, without significant increase in required processing power.

According to the present invention, there is provided a method of processing a data signal comprising receiving a data sequence incorporating PSK symbols, separating the data sequence into bits of symbols, assigning a confidence value to each bit in a symbol, and effecting convolutional decoding of the bit stream associated with the assigned confidence values.

In this way, the method may provide enhanced performance of the decoding operation with reduced block error rate.

The method may include any one or more of the following features:-

- assigning a confidence value comprises mapping symbols to binary bits by means of a Gray code;
- incorporating data on the mapping determination in a look-up table for reference;
- re-coding hard decisions as an (I,Q) pair and taking soft decisions therefrom;
- demodulation by decision feedback equalisation with whitening matched filtering;
- using a digital processor for equalisation;
- using dedicated signal processing hardware for equalisation;
- de-interleaving, de-puncturing and incremental redundancy steps before convolutional decoding.

Another aspect of the present invention provides a computer program product directly loadable into the internal memory of a digital computer, comprising software portions for performing the steps of the method of the present invention when said product is run on a computer.

Another aspect of the present invention provides a computer program for performing the steps of the method of the present invention when said program is run on a computer.

The present invention also provides a carrier, which may comprise electronic signals, for a computer program embodying the present invention.

A further aspect of the present invention provides electronic distribution of a computer program of the method of the present invention.

A further aspect of the present invention provides apparatus for processing a data signal comprising means to receive a data sequence incorporating PSK symbols, means to separate the data sequence into bits of symbols, means to assign a confidence value to each bit in a symbol, and means to effecting convolutional decoding of the bit stream associated with the assigned confidence values.

A further aspect of the present invention provides a system for processing data signal incorporating such apparatus.

A further aspect of the present invention provides a look-up table derived from a method of the present invention or from apparatus of the present invention.

A further aspect of the present invention provides a method for using such a look-up table and apparatus for using such a look-up table.

The present invention is generally applicable to 8-level PSK signals, and particularly suited to digital cellular communications for example using the GSM standard especially incorporating the EDGE services.

It is also applicable to high-order Gray-coded constellation points (for example for CDMA 2000 standard and the UMTS standard) and to data coding and forward-error-correction. Furthermore, it is also applicable to digital video broadcasting and OFDM modulation.

In order that the invention may more readily be understood, a description is now given, by way of example only, reference being made to the accompanying drawings, in which:-

Figure 1 is a block diagram of a radio receiver for a handset incorporating the present invention;

Figure 2 is a block diagram of an equaliser incorporating the present invention;

Figure 3 is a block diagram of the remainder of the signal processing of the present system;

Figure 4 is a schematic diagram of 8-PSK modulation; and

Figure 5 shows a block error testing system.

There is shown in Figure 1 a dual-conversion receiver architecture for a UMTS/GSM receiver with EDGE services capability. GSM signals received at antenna 10 pass to low noise amplifier 11 and onto mixer 12 to be input to a low intermediate frequency unit 13 of 100 kH (contrasting with a zero intermediate frequency for the CDMA node), thereby to allow integration of the channel filters (in this architecture channel filtering is performed digitally) without the performance loss associated with zero-IF receivers for narrowband systems, then passing to amplifier 14, and mixer 15, and on to A/D unit 16.

Details of the GSM/EDGE standard are disclosed in the 3G UMTS standard, see for example the Technical Specification published under reference 3GPP TS 45.004, v 4.2.0 (2001-11).

A cellular telephone handset is capable of receiving EDGE modulated signals and the EDGE (Enhanced Data-rates for GSM Evolution) protocol builds upon the successful GSM cellular telephone standard in order to give faster communication links while using the same amount of radio spectrum as GSM. The faster data transfer makes such actions as web browsing run at a tolerable speed on a handset; WAP handsets, which allowed web browsing using traditional GSM modulation have been found to be extremely slow.

GSM is a digital transmission scheme that uses time-division-multiple-access to allow up to eight handsets to simultaneously use the same 200 kHz frequency channel. When making a call, the transmitter at one end (and the corresponding receiver at the other end) is turned on for

a burst lasting 156.25 bits at a bit rate of 270.833 kbits/s and left off for seven further burst periods before being turned on again. The modulation scheme is Gaussian-filtered minimum-shift-keying (GMSK), a form of frequency modulation.

The bit rate is sufficiently high that typical propagation conditions result in inter-symbol-interference (ISI). To allow for this, a training sequence 20 (a predefined sequence of bits) is transmitted as part of the burst. The signal received when this training sequence is due is used to work out how the radio propagation conditions have distorted the signal, as well as providing timing and phase references using estimator 21.

As well as several copies of the transmitted signal (all at different times and with different amplitudes and phases) there is also noise, be it thermal noise or interference from other cells using the same frequency.

Equaliser 22 determines what was the transmitted sequence, by working out a likely sequence of bits given a received sequence of samples and the ISI deduced from the training sequence 20.

For GSM, a popular equaliser is the Viterbi equaliser, which relies on each bit only affecting a small number of bits after it (a window, typically up to 9 bits long). By working at the probabilities of all possible sets of 9 bits being transmitted given the received sequence and the expected inter-symbol-interference, the most likely set has the correct first bit.

This bit is then fixed, and the remaining bits are shifted down, with a new unknown bit and corresponding received samples being considered in the window. The number of different sequence probabilities which must be simultaneously considered is $2^9 = 512$ (with a different 512 for each bit). By considering all possible sequences within the window, the Viterbi equaliser gives very good results.

Even with the Viterbi equaliser, results are not perfect. As one gets further from the training sequence, the risk of bit errors gets larger. For this reason, the GSM standard places important bits close to the training sequence 20 and less important bits further away at the ends of the burst.

Under typical urban conditions, the minimum acceptable standard is to have 8 % of bits decoded wrongly. This gives rise to clicks and whistles on top of the voice one is listening to, but it is generally tolerable.

For sending digital information, further error correction is necessary. Convolutional coding is used, typically 1/2-rate (so that for every information bit to be transmitted, a sequence of two bits is actually transmitted). Convolutional coding is more complicated than simple repetition, and the performance improvement correspondingly better than repetition.

One measure of the quality of a coding scheme is the "minimum distance" – how many bits in a coded sequence have to be wrong before another valid coded sequence has been created. Where a bit is received in error, it does not fit in with the bits before or after it. The Viterbi maximum-likelihood-sequence algorithm is therefore applied to decode the bit sequence.

On a radio channel, bit errors are likely to occur in bursts, for example because the equaliser 22 has moved too far from the training sequence 20, or because of a spark of noise, or because of a short fade. Since convolutional coding uses nearby bits to correct a bad bit, it is useful to interleave the bits, so that the nearby bits for decoding are not nearby for propagation.

Because of all the overheads of training sequences, convolutional coding, control information and the 1/8 duty cycle, the 270.833 kbit/s raw bit rate translates to 9600 data bits/s when using a GSM data link.

EDGE introduces two changes to the GSM standard: more options for data coding, and modulation that is more efficient.

Coding

When propagation conditions are known to be good enough, so that the raw bit error rate is much less than 8 %, weaker convolutional coding may be used (or none at all). While it is possible to use (for example) a

2/3-rate convolutional coder, this is not the approach taken by the EDGE standard. Instead, it uses the 1/2-rate coder, but then discards a portion of the output bits, evenly distributed, in a process called puncturing. This allows bit-rates to be increased to 17.6 kbit/s.

Modulation

As well as GMSK, the option for 8-symbol phase-shift-keying (8PSK) is introduced. This is done at the same symbol rate (270833/s) and in the same modulation bandwidth (200 kHz), but since three bits can be sent per symbol, the raw bit rate is tripled to 812.5 kbit/s. While retaining the 1/8 duty cycle (hence the amount of channel capacity allocated to one user), the useful data rate increases to 59.2 kbit/s when conditions are sufficiently good.

One downside to the modulation change is that a Viterbi equaliser would need to keep track of 8^9 = 134217728 sequence probabilities, and even with the advances in computing power since the introduction of GSM it would be impractical to perform this many calculations for each symbol being decoded. Demodulation is therefore done with a different technique, for example a decision feedback equaliser with whitening matched filter. After depuncturing and deinterleaving, a Viterbi decoder is still the best choice for removing the convolutional coding.

Because power efficiency is important in battery-powered cellular telephones, the receiver is only active when a burst intended for the handset is expected. The analogue radio parts are powered up during the burst. The digital signal processing essentially is delayed until the burst is complete, with the whole burst being processed as a single vector.

Because equalisation at equaliser 22 is done from the training sequence 20 outwards (so both forwards and backwards in time), the implementation must use memory, and this is easiest in the digitial domain. The equaliser algorithm may be implemented as software in a digitial signal processor, but it could alternatively be implemented as

dedicated signal processing hardware. The output from equaliser 22 is 116 bits (GMSK) or symbols (8PSK) namely 157.25 less the training sequence and guard spaces as shown in Figure 2.

The interleaving 30, depuncturing 31 and incremental redundancy blocks 32 follow as shown in Figure 3. The symbols-to-bits mapping increases the number of bits fed to the deinterleaver 30 from 116 to 348.

Even in the absence of soft decisions from the equaliser, the convolutional decoder 33 works most effectively if it is arranged to take soft inputs, because the values of the punctured bits are unknown, rather than being received as either 1 or 0 (subject to noise and interference).

The decoder 33 can take in (for example) +1.0 as being reasonably confident logic 1, -1.0 as being reasonably confident logic 0, and 0.0 to indicate that a bit is equally likely to be 1 or 0.

The present invention ensures improved mapping of symbols to bits, taking advantage of the fact that the convolutional decoder takes soft inputs.

Examination of the PSK symbols shows that some of the decoded bits are known with more confidence than other bits because even if the correct symbol turned out to be one next to the one selected by the equaliser, one of the bits would remain unchanged. Taking the "reasonably confident" bits to have values of ± 1.0, the "very confident" bits were assigned values of $\pm\alpha$, where α is a value greater than 1.0. The optimum value for α depends on the propagation conditions (probably the relative strengths of inter-symbol-interference after equalisation and noise/interference). Since it is difficult to measure what the propagation conditions are, a fixed value of α is proposed, the value being determined by system simulation beforehand. The value chosen is a compromise, and could be weighted towards parts of the standard that are considered difficult to meet, or towards conditions that are most likely to occur in practice.

Where the set of symbols and bits is more complicated (eg 16QAM or 64QAM), there might need to be more levels of confidence, but they can still be put into a lookup table from "symbol decoded by equaliser" to "probability that each bit is a 1 or 0".

If the equaliser is able to produce greater information, where it thinks the constellation point is on the complex plane rather than which symbol it thinks is closest, even better results will be obtained by interpolating between specified points in the lookup table.

Essentially, the present invention is a development from the conventional system involving a decision-feedback equaliser which produces hard decisions and chooses the most likely symbol given the received signal, but provides no further information about how close the received signal was to that symbol or whether there was another symbol almost as likely. In this conventional system, there is a direct translation between symbols and the binary patterns they represent. One such system therefore took hard symbol decisions and produced equally hard binary output. Although this conversion is correct, it does not indicate the different degree of confidence in which bits are held, assuming that the symbol might be in error.

With 8-PSK modulation, the symbols are equally spaced around a circle, as shown in Figure 4. In order to reduce the bit error rate should transmitted symbol 6 be mistakenly decoded as symbol 5, these symbols are mapped to binary bits by means of a Gray code, shown in Table 1.

8-PSK Symbol	Bit 0	Bit 1	Bit 2
0	1	1	1
1	0	1	1
2	0	1	0
3	0	0	0
4	0	0	1
5	1	0	1
6	1	0	0
7	1	1	0

Table 1

If one decodes symbol 5 in the presence of noise, it could be that the transmitted symbol was actually 4 or 6. Looking at the binary patterns in Table 1, it is clear that whether the transmitted signal was 4, 5 or 6, bit 1 is still be zero. Bit 0 or bit 2, which symbol 5 would decode as ones, might be zero if the transmitted symbol was actually 4 or 6. Therefore, when symbol 5 is received, bit 1 is known to be zero with greater confidence than one knows bits 0 and 2 to be ones.

A similar analysis is applied to all eight symbols. Writing a confident mapping of one as $+\alpha$ over the normal value of +1, and confident mapping of zero as $-\alpha$ over the normal value of −1 there results an improved mapping table, shown as Table 2 (which indicates improved mapping of 8-PSK bits to give softer input to convolutional decoder). With α being some value greater than unity, the hard decisions of 8-PSK symbols can therefore be transformed into softer decisions that are fed to the convolutional decoder. This technique has no impact on the raw bit error rate, but can significantly improve the coded bit- and block-error-rates.

8-PSK Symbol	Bit 0	Bit 1	Bit 2
0	1	α	1
1	−1	α	1
2	$-\alpha$	1	−1
3	$-\alpha$	−1	−1
4	−1	$-\alpha$	1
5	1	$-\alpha$	1
6	α	−1	−1
7	α	1	−1

Table 2

The optimum value for α depends on propagation conditions. Under static sensitivity conditions, the optimum value seemed to be around 3.4, delivering up to 4 dB reduction in SNR required to achieve the specified block-error-rate. Since the toughest test was TU50 co-channel, α must be optimised for those conditions. From simulations summarised in Table 3

(which shows benefits observed for improved decoding under TU50 Co-channel conditions), it was concluded that the optimum value for α is 1.7, with an improvement in receiver performance around 0.7 dB. This is a small improvement, but significantly advantages.

Coding Scheme	C/I ratio of interest (dB)	Optimum value for α	Benefit (dB)
ECSD 28.8 NT	13 – 15	1.7	0.5
EGPRS MCS-5	13 – 15	1.9	1.0
ECSD 28.8 T	15 – 17	1.7	0.5
EGPRS MCS-6	15 – 17	1.7	1.0
ECSD 32 T	16 – 18	1.7	0.4
ECSD 43.2 NT	18 – 20	1.7	0.5
EGPRS MCS-7	21 – 23	No optimum value	0.4
EGPRS MCS-8	21 – 23	No optimum value	0.1
EGPRS MCS-9	23 – 25	No optimum value	negligible

Table 3

Thus, the present invention concerns the radio receiver used in cellular telephones supporting the EDGE standard (enhanced data rates for GSM evolution). In this standard, data bits are convolutionally coded and then Gray coded onto 8-PSK symbols. The Grey coding ensures that only one bit error occurs if (due to noise) the received symbol is adjacent to the symbol transmitted.

As another example, if the transmitted symbol was 110, and the receiver made an error and chose an adjacent symbol (either 111 or 100), in either case there would only be one bit in error.

Hard decisions are generally used, in that the demodulator has to choose one symbol – it cannot say that the signal is somewhere between two of the symbols. This is because the demodulator has many things to handle when sorting out inter-symbol-interference (a major problem in GSM/EDGE).

These symbols are then converted into a bit stream for feeding to the convolutional decoder. In one conventional system, the conversion

done is direct binary to integer (using the mapping 1 maps to +1 and 0 maps to –1).

The present invention involves an improved conversion which makes the observation that the bits in a symbol are known to different levels of confidence. If one looks at symbol 110, it might really be 111 or 100. The leading 1 is known much more strongly than the other two bits. It should therefore be mapped to some other value, more positive than 1. Let this value be α, a constant value greater than or equal to 1. 110 then maps to α, 1, 0). The full mapping table becomes:-

000→ (-α, -1, -1)
001→ (-1, -α, 1)
010→ (-α, 1, -1)
011→ (-1, α, 1)
100→ (α, -1, -1)
101→(1, - α, 1)
110→(α, 1, -1)
111→(1, α, 1)

These can then be used by convolutional decoder 33 as soft decisions, giving a much better performance.

When α is 1.0 (the reference performance) MCS-5 coding with a co-channel interferer 8 dB below the wanted signal, a block error rate of 0.311 is observed. If α is increased to 3.4, the block error rate drops to 0.044. This is equivalent to an improvement in signal-to-interferer ratio of more than 2dB. Values of between 3 and 4 seem to give the best results, although it is not too critical.

Thus the data on the mapping determination is incorporated in a look-up table which is referenced by units of the receiver as appropriate.

Thus, in the present invention, Gray coding ensures that only one bit error occurs if (due to noise) the decoded symbol is adjacent to the symbol transmitted, e.g. the adjacent symbols to 110 are 111 and 100.

Conventionally, the demodulator normally makes a hard decision on each symbol.

In the invention, it is proposed that soft decisions are made by the demodulator, assigning increased confidence to the bit in a symbol which is the same in adjacent symbols. In the example above, the first bits is known to be 1 with a much higher degree of certainty than the value of the other two bits. For this example, using binary to integer mapping (so that 1 maps to +1 and 0 to –1) the symbol is represented as (α, 1, -1). These values are then used by a standard convolutional decoder. Values of α between 3 and 4 have been found to give particularly good results.

The known prior art takes the starting position that one has I and W received signals (with no mention of how multipath propagation, which leads to inter-symbol interference, has mitigated). They only establish that one can generate soft decisions on all bits, depending on where the measured (I,Q) vector ended up.

The present invention starts with the output from a multipath equaliser which produces hard decisions, thereby losing useful information, good results being obtained from an equaliser that generates soft decisions.

The present invention takes the hard decisions, re-codes them as an (I,Q) pair, and then takes soft decisions from that. In this way the present invention gets soft decisions out of a decision-feedback equaliser. The present invention softens the decisions made by equalisers which produce hard decisions.

This invention may provide significant reduction in block error rate, without significant increase in required processing power.

The present invention is particularly applicable to the implementation of receivers for EDGE phones (enhanced GSM data rates), and other receivers for standards using gray-coded symbols.

In Figure 5, there is shown a bit-and block-error-rate testing system.

It was considered desirable to be able to measure raw (uncoded) bit error rate and block-error-rate for EDGE coded data in the same simulation to allow direct comparsions of performance. This meant using a system in Figure 5. The new blocks are shown with shadowing. The difference as far as bit-error-rate calculations are concerned is that the bit sequence being used is the output of convolutional encoder 33 fed with random bits, rather than raw random bits. This does not make a significant difference because the demodulator is unaware of forbidden bit-sequences, but there might be some change in the statistics of transitions.

To determine if this would alter the simulated performance of the system, static sensitivity tests were run with both random bits and random bits fed through the EDGE encoder from which it is evident that signals in the range –115 dBm to –100 dBm show little difference between raw bits for coded and uncoded systems is small.

CLAIMS

1. A method of processing a data signal comprising receiving a data sequence incorporating PSK symbols,

separating the data sequence into bits of symbols,

assigning a confidence value to each bit in a symbol, and

effecting convolutional decoding of the bit stream associated with the assigned confidence values.

2. A method according to Claim 1 wherein the step of assigning a confidence value comprises mapping symbols to binary bits by means of a Gray code.

3. A method according to any preceding claim comprising incorporating data on the mapping determination in a look-up table for reference.

4. A method according to any preceding claim comprising re-coding hard decisions as an (I,Q) pair and taking soft decisions therefrom.

5. A method according to any preceding claim comprising demodulation by decision feedback equalisation with whitening matched filtering.

6. A method according to any preceding claim comprising using a digital processor for equalisation.

7. A method according to any of Claims 1 to 5 using dedicated signal processing hardware for equalisation.

8. A method according to any preceding claim comprising de-interleaving, de-puncturing and incremental redundancy steps before convolutional decoding.

9. A method substantially as hereinbefore described with reference to and/or as illustrated in any one or more of the Figures of the accompanying drawings.

10. A computer program product directly loadable into the internal memory of a digital computer, comprising software code portions for performing the steps of any one or more of Claims 1 to 9 when said product is run a computer.

11. Apparatus for processing a data signal comprising means to receive a data sequence incorporating PSK symbols,

means to separate the data sequence into bits of symbols,

means to assign a confidence value to each bit in a symbol, and

means to effecting convoluntional decoding of the bit stream associated with the assigned confidence values.

12. Apparatus according to Claim 11 wherein the confidence assign means comprises means to map symbols to binary bits by a Gray code.

13. Apparatus according to Claim 11 or 12 comprising a look-up table incorporating data on the mapping determination for reference.

14. Apparatus according to any of Claims 11 to 13 comprising means to re-code hard decisions as an (I,Q) pair and means to take soft decisions therefrom.

15. Apparatus according to any of Claims 11 to 14 comprising demodulation by decision feedback equalisation with whitening matched filtering.

16. Apparatus according to any of Claims 11 to 15 comprising a digital processor for equalisation.

17. Apparatus according to any of Claims 11 to 16 comprising dedicated signal processing hardware for equalisation.

18. Apparatus according to any of Claims 11 to 17 comprising means to de-interleave, depuncture, and effect incremental redundancy before convolutional decoding.

19. Apparatus for processing a data signal substantially as hereinbefore described with reference to and/or as illustrated in any one or more of the Figures of the accompanying drawings.

20. A look-up table produced by the method of any one of Claims 1 to 9 or the apparatus of any one of Claims 11 to 19.

ABSTRACT

SIGNAL PROCESSING METHOD AND APPARATUS

In a dual-conversion UMTS/GSM receiver with EDGE services capability, a data sequence incorporating PSK symbols is separated into bits which are assigned confidence values and input to convoluntional decoder 33 to provide improved decoding.

(Figure 3)

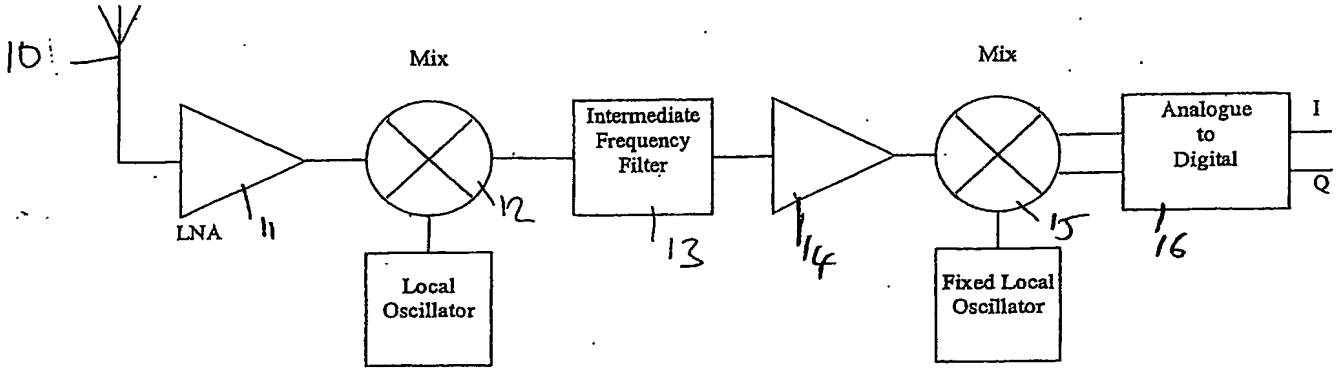


FIGURE1

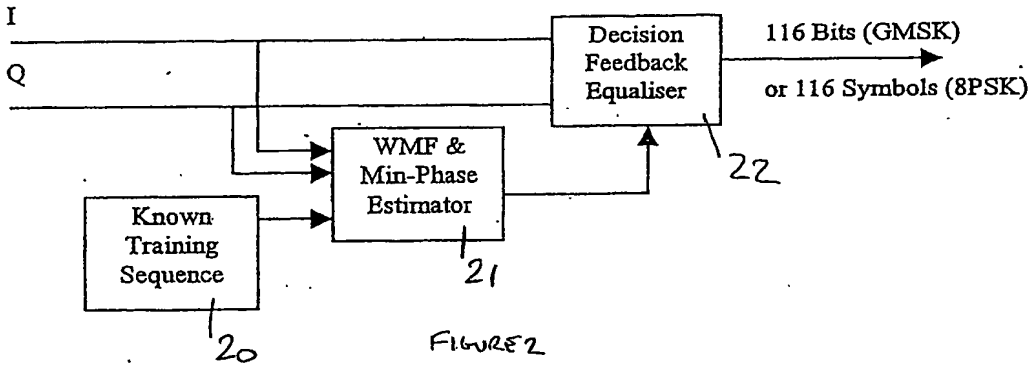


FIGURE2

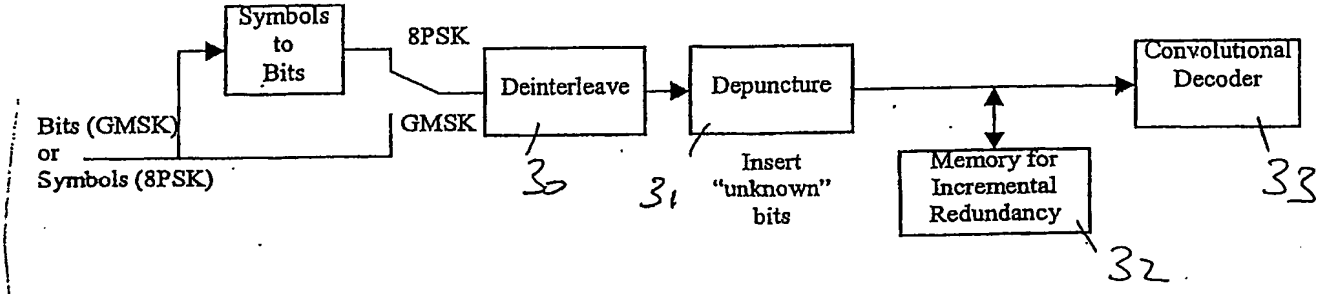


FIGURE 3

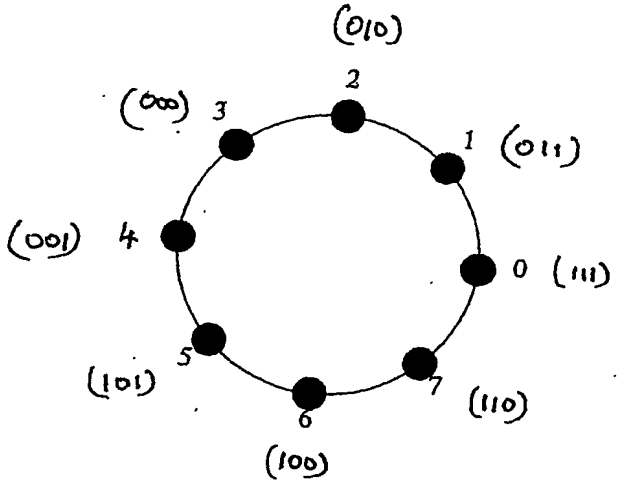


FIGURE 4

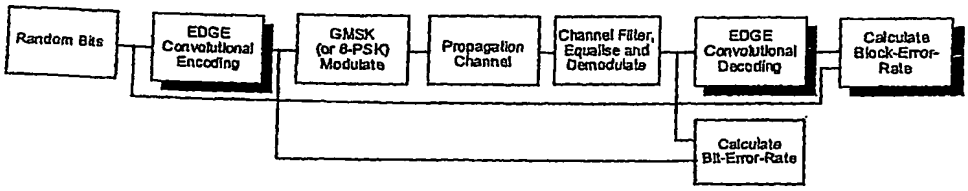
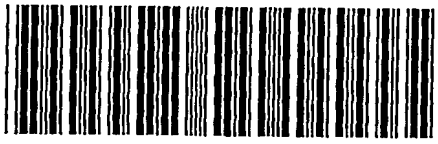


FIGURE 5

PCT Application
IB0305658